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Current Projects and Related Research

Abstracts of papers presented November 28–30, 1995

John Sibert & Mary Nunn, Editors

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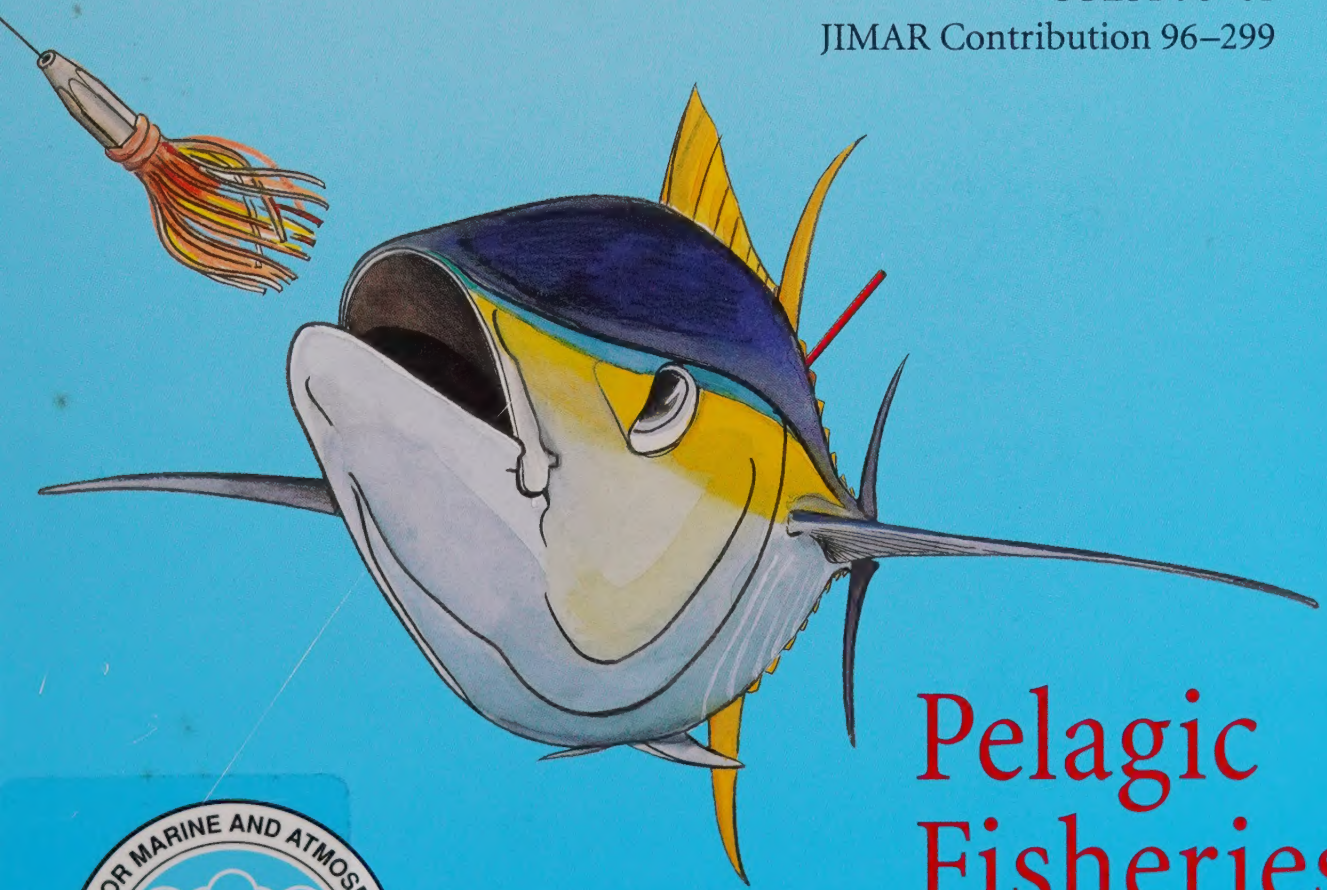

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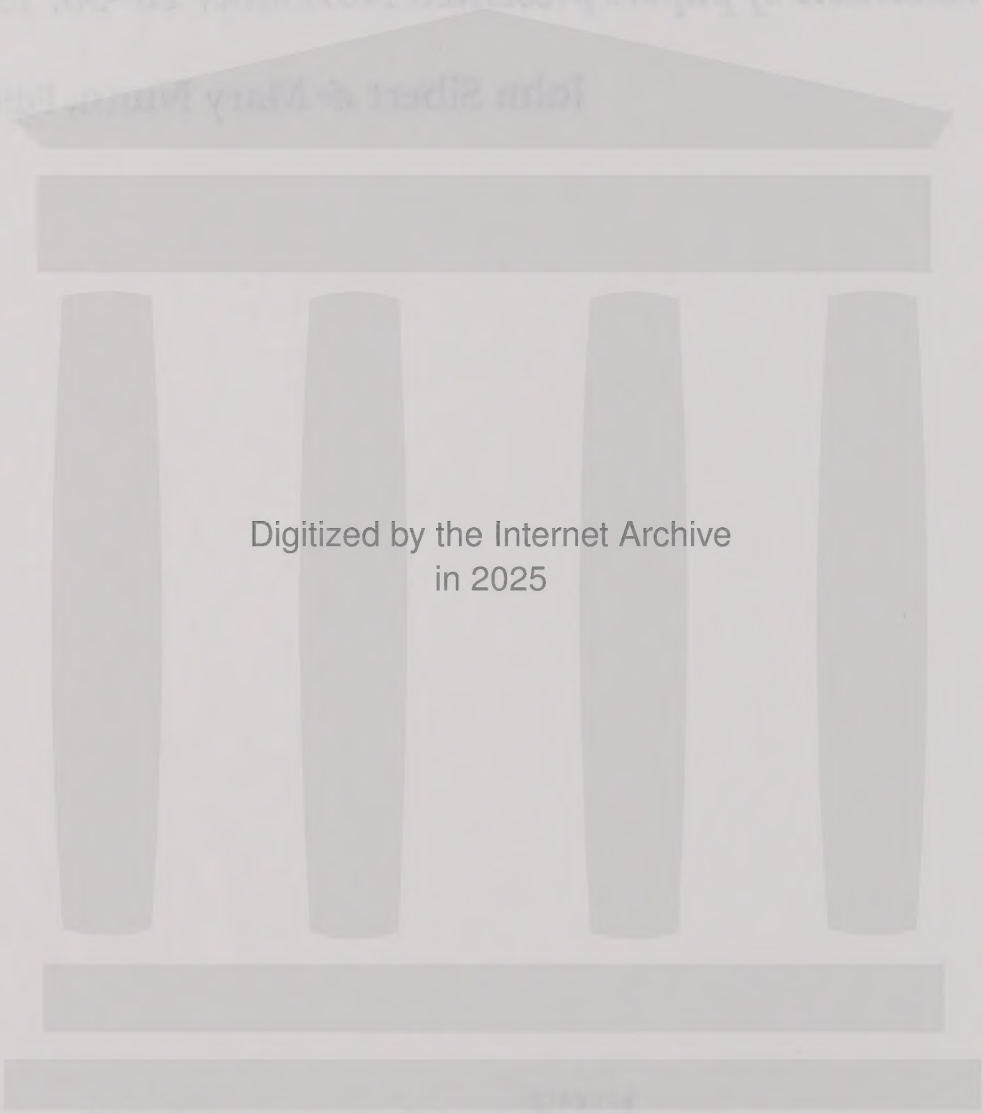
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INTRODUCTION

John Sibert
Program Manager
Pelagic Fisheries Research Program
Joint Institute for Marine and Atmospheric Research

The Pelagic Fisheries Research Program (PFRP) was established in 1992. Its mission is to provide basic scientific information to the Western Pacific Regional Fishery Management Council (WPRFMC) for use in development of management policies for pelagic fisheries. The first PFRP projects were established in late 1993, and work on these projects began in 1994. The PFRP currently supports more than 30 research projects. The subject matter includes oceanography, biology, statistics, economics and anthropology. The geographic area encompassed by PFRP includes the entire WPRFMC area, approximately 1.5 million square miles, including American Samoa, Guam, Hawaii, Commonwealth of the Northern Mariana Islands, and other United States Pacific territories.

PFRP principal investigators meet twice a year to present research plans and discuss preliminary results. At the May 1995 PI meeting, it became clear that significant research results were beginning to accrue, and a major presentation was planned for November of 1995. Nearly all of the PFRP PIs made presentations at the November 1995 meeting, ranging in content from research plans of recently funded new projects to mature results of work that has been in progress for nearly two years. Outside investigators were also invited to make presentations providing regional context for the PFRP projects. Speakers from the South Pacific Commission (Nouméa, New Caledonia), Inter-American Tropical Tuna Commission (La Jolla, United States), ORSTOM, IFREMER, EVAM (Papeete, French Polynesia), and CSIRO (Hobart, Australia) presented research results and outlined research programs on pelagic fisheries conducted by their organizations. This report, containing abstracts of all PFRP projects presented at the November meeting, is the first public presentation of PFRP results.

Except where noted, all research reported herein is funded by Cooperative Agreement Number NA37RJ0199 from the National Oceanic and Atmospheric Administration. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its subagencies.

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** Abstract not submitted

PELAGIC FISHERIES RESEARCH PROGRAM

Workshop Agenda
November 28-30, 1995, Asia Room
East-West Center, 1777 East-West Road
Honolulu, Hawaii

Tuesday, November 28, 1995

08:45 Welcome

OCEANOGRAPHY

09:00 Mean Flow and Eddy Statistics for the Hawaii EEZ Inferred from the Pelagic Fisheries Drifters Array ..... P. Flament, C. Lumpkin, J. Firing

09:30 A Numerical Study of Ocean Circulation and Pelagic Fisheries Around the Hawaiian Islands ..... B. Qiu, D. Koh, P. Flament

10:00 *Break*

10:30 Evaluation of Remote Sensing Technologies for the Identification of Oceanographic Features Critical to Pelagic Fish Distributions Around the Hawaiian Archipelago ..... G. Mitchum, J. Polovina

11:00 Hawaii-Based Swordfish Longline Vessel Distribution and Catch from 1991 to 1994: Relation to Observed Thermal Structure & Lunar Periodicity ..... K. Bigelow, C. Boggs

11:30 Relationship Between Tuna and Environment: A Model to Explain the Distribution of Skipjack Tuna in the Tropical Pacific Ocean ..... P. Lehodey

12:00 *Lunch*

MOVEMENT

13:30 Prospects for Development of Fully Integrated Models for Pelagic Fishery Management ..... J. Sibert

14:00 Design of Tag-Recapture Experiments for Estimating Yellowfin Tuna Stock Dynamics, Movement and Fishery Interactions ..... P. Bills

14:30 Laboratory and Field Research to Enhance Understanding of Tuna Movements and Distribution, and to Improve Stock Assessment Methods ..... R. Brill

15:00 *Break*

15:30 A Regional Simulation Model for Western Pacific Tuna Fisheries ..... M. Bertignac

16:00 Tagging Program for Seamount Yellowfin and Bigeye Tuna ..... K. Holland

16:30 A "Pop-Up" Satellite Transmitting Archival Tag (PSTAT) for Studying Swordfish Movement and Behaviour ..... J. Gunn, C. Boggs

16:45 General discussion

17:30 ***Dinner Reception, EW Center, garden level, Wailana Room***

Wednesday, November 29, 1995

ECONOMICS

08:00 Hawaii Fleet Industry & Vessel Economics (HIFIVE):
- Introduction
- Hawaii Pelagic Market Channels and Cointegration Analysis ..... S. Pooley, R. Ito

08:15 - Fishing Power, Harvest Capacity, and Fishing Effort: An Economic Analysis of Catch Rates in Hawaii's Longline Swordfish Fishery ..... M. Travis

08:45 - Cost-Earnings Analysis of the Hawaii-Based Domestic Longline Fleet ..... M. Hamilton

09:15 - Longline Technology and Regulatory Policy in Hawaii ..... R. Curtis, S. Pooley

09:45 - Cost-Earnings Analysis of Hawaii's Commercial Troll and Handline Fisheries ..... M. Hamilton, S. Huffman

10:00 *Break*

10:30 A Multilevel and Multiobjective Programming Model of Hawaii Commercial Fisheries ..... U. Chakravorty

11:00 Quality and Product Differentiation as Price Determinants in the Marketing of Fresh Pacific Tuna and Marlin ..... P. Bartram, P. Garrod, J. Kaneko

Wednesday, November 29, 1995 (cont)

11:30 The Contribution of Tuna Fishing, Transshipment, and Processing to the Economies of American Samoa, Commonwealth of the Northern Marianas and Guam ..... M. Hamnett

12:00 ***Lunch***

13:30 Economics of Recreational Fishing for Pelagics in Hawaii ..... S. Pooley, K. McConnell

13:45 Economic Interactions Between United States Longline Fisheries ..... M. Travis, I. Strand

SOCIOCULTURAL

14:00 The Hawaii Troll and Handline Fishery: Fishermen's Motivations and Fishing Action ..... M. Miller

14:30 Coordinated Sociocultural Investigation of Pelagic Fishermen in American Samoa, Commonwealth of the Northern Mariana Islands, and Guam ..... M. Hamnett and Colleagues

14:45 General discussion

15:00 ***Break***

15:30 Overview of Atlantic Highly Migratory Species Research ..... R. Stone

16:00 Tuna Research in French Polynesia ..... F.X. Bard

Acoustic Tagging and Echo-Survey Together: A New Approach to Study Tuna Behavior ..... E. Josse

16:30 Pelagic Fisheries Research at the South Pacific Commission ..... J. Hampton

Thursday, November 30, 1995

GENETICS

08:00 Analysis of Pacific Blue Marlin and Swordfish Population Structure Using Mitochondrial and Nuclear DNA Technologies:

- Blue Marlin Population Genetic Structure in the Pacific Ocean: Analyses of Mitochondrial and Nuclear DNA ..... J. Graves, J. McDowell V. Buonaccorsi

08:30

- Global Population Structure of the Swordfish, *Xiphias gladius*, as Revealed by Analysis of the Mitochondrial DNA ..... B. Block, C. Reeb, P. Rosel

09:00 Genetic Analysis of Tuna Populations ..... P. Grewe

10:00 ***Break***

BIOLOGY & STATISTICS

10:30 Local Pelagic Catch and Effort Data Analysis and Integrated Modeling to Quantify the Effects of Local Fisheries on Fish Availability:

- Performance Indices for Hawaii's Troll and Handline Fisheries ..... C. Boggs, D. Curran X. He, Q. Yang

11:00

- Simulation Modeling and Time-Series Analysis of Catch and CPUE in Hawaii's Tuna Fisheries ..... X. He, C. Boggs

11:30 Stock and Fishery Dynamics of Yellowfin Tuna, *Thunnus albacares*, in the Western and Central Pacific Ocean: An Integrated Model Incorporating Size and Spatial Structure ..... J. Hampton, D. Fournier

12:00 ***Lunch***

13:30 Automated Monitoring of Tuna Yellowfin at Hawaiian Fish Aggregation Devices (FADS) ..... P. Klimley, C. Holloway

14:00 The Reproductive Biology and Spawning Behavior of Yellowfin Tuna: Implications to Gear Vulnerability and Fishery Interaction ..... D. Itano

14:30 Pelagic Fisheries Research in the Eastern Pacific Ocean by the Tuna-Billfish Program of the Inter-American Tropical Tuna Commission, with Emphasis on Tuna Reproduction ..... K. Schaefer

15:00 ***Break***

15:30 Feasibility of Airborne Laser Devices for Pelagic Fish Surveys ..... C. Schoen

16:00 Preliminary Estimation of Shark Bycatch by the Hawaii Longline Fishery ..... X. He

16:15 Aspects of the Ecology of the Red Squid, *Ommastrephes bartramii*, a Potential Target for a Major Hawaiian Fishery ..... R. Young, J. Hirota

16:30 Yellowfin Otolith Chemistry ..... J. Gunn

Mean Flow and Eddy Statistics for the Hawaii EEZ Inferred from the Pelagic Fisheries Drifters Array

Pierre Flament, Claude Lumpkin, and June Firing

Department of Oceanography
University of Hawaii at Manoa

The Central Pacific Drifter Array, consisting of seventy drifting buoys, is in the process of being deployed to map the oceanic flow in the Hawaiian Exclusive Economic Zone. Fifty-five drifting buoys have been deployed in September 1994, October 1994 and August 1995 in successive clusters south of Maui and west of Kona. The remaining twenty-five buoys will be deployed twice monthly in the Alenuihaha channel until October 1996.

The buoys consist of a 35-cm diameter surface float containing batteries and an ARGOS transmitter, a 12-m tether, and a holey sock drogue of 92-cm diameter and 6.4 m length. The average life of the buoys is one year. Locations and water temperatures are collected daily with a 1/3 duty cycle. Once complete, the data returned by this project will result in a five-fold increase of the number of current measurements available in the lee of the Hawaiian islands and over the northwest ridge.

The drifter trajectories reveal an intense mesoscale eddy field west and northwest of the Hawaiian islands. Strong cyclonic eddies, corresponding to uplifted thermoclines, are observed in the lee north of 19°30N, whereas strong anticyclonic eddies, corresponding to deepened thermoclines, occur preferably south of this latitude, at the northern boundary of the North Equatorial Current. It is hypothesized that the cyclonic eddies result from upward Ekman pumping associated with the strong wind shear lines in the lee of the islands, while the anticyclonic eddies result from a dynamical instability of the NEC as it reaches the big island.

The average velocity field reveals a pair of elliptical counter-rotating gyres westward of the islands, the cyclonic one to the north of 19°N, the anticyclonic one to the south. The major axes of the gyres extend approximately from 157°W to 160°W. A strong narrow eastward counter current exists along 19°N. These large gyres are interpreted to be the average expression of individual cyclonic and anticyclonic eddies spun up in the lee of the islands, which eventually drift westward and decay. The map of average trajectory curvature, related to eddy vorticity, shows that individual cyclonic eddies dominate north of the counter current, while anticyclonic vorticity dominate south; as a result the mean thermocline depth is reduced north and increased south.

The map of velocity variance shows more than a ten-fold increase of eddy kinetic energy in the lee of the islands, as a result of the processes hypothesized above. Variance is very small in the NEC at 10°N to 14°N, and small northeast of the islands.

Lagrangian statistics (i.e., following particles as opposed to spatially gridded) yield single-particle eddy diffusivities. These statistics have been computed over 90-day segments of the tracks, separately over four non-overlapping regions: the NEC south of 18°N (region 1), the lee of the islands between 18°N and 22°N (region 2), the northwest ridge north of 22°N and west of 161°W (region 4), and the windward (region 3). The eddy-diffusivities appear to vary spatially up to 2.5-fold, and are anisotropic west of the islands. Typical values in regions 1 and 3 are 4000-5000 m^2sec^{-1}, similar to values found by colleagues in the North Atlantic (shown by circles), but increase to 8000-12000 m^2sec^{-1} in regions 2 and 4 (multiply by 0.75 to express eddy diffusivities in nautical miles squared per month).

A Numerical Study of Ocean Circulation and Pelagic Fisheries Around the Hawaiian Islands

Bo Qiu, Deborah Koh, and Pierre Flament

Department of Oceanography
University of Hawaii at Manoa

A model of the upper layer circulation in the North Pacific has been developed to study currents around the Hawaiian Islands. The focus of this modeling work is to understand how the presence of the Hawaiian Ridge and other islands interact with the southwestward interior flow. The goal of our work is to clarify the cause of seasonal and interannual variability of the ocean circulation and its influence on the movement of pelagic fish near the Hawaiian Islands. The model has a wind-driven upper layer, an unventilated lower layer, and an inert abyssal layer (a 2.5-layer, reduced-gravity system). The model's domain covers the North Pacific basin with variable spatial resolution which focuses on the region around the Hawaiian Islands.

As a first step in this study, we have investigated the circulation driven solely by surface wind using Hellerman and Rosenstein's (1983) monthly climatological wind data set. The seasonal signal of ocean circulation on both the windward and leeward sides of the Hawaiian Islands has a large, semi-annual signal. This signal is a combination of the annual Rossby waves originated from the California coast and the waves regionally induced east of the Hawaiian Island. These semi-annual fluctuations not only change the along-Island flow directions but also reverse the through-channel flows between the four Hawaiian Islands. The possible effects of these seasonally varying ocean currents on the movement of passive fish larvae will be presented.

Evaluation of Remote Sensing Technologies for the Identification of Oceanographic Features Critical to Pelagic Fish Distributions Around the Hawaiian Archipelago

Gary Mitchum[1] and Jeffrey J. Polovina[2]

[1]Department of Oceanography, University of Hawaii at Manoa
[2]National Marine Fisheries Service, Honolulu Laboratory

Our project received its initial funding in February of 1995. A review of the overall project goals and timelines will be presented, along with a status report showing that we are on schedule. The results to be reported focus on a physical description of the statistics of the mesoscale variability in the vicinity of the Hawaiian islands. In this context, mesoscale variations are defined as having time scales less than 200 days and spatial scales of tens to hundreds of kilometers. The talk will conclude with a brief description of work in progress and a plan for the coming year.

The mesoscale description we will present is primarily from 3 satellite altimeters: GEOSAT, TOPEX/POSEIDON (T/P), and ERS-1. The GEOSAT data are from the time period 1986-1988, T/P and ERS-1 span 1992-present and 1992-1993, respectively. The T/P and ERS-1 descriptions are very consistent, showing, for example, variability due to waves and eddies in the lee of the Hawaiian islands, variations near the Kuroshio extension, and a region of very low mesoscale energy to the northeast of the islands. The seasonal evolution of these features has also been evaluated, and shows an out-of-phase relationship between the high energy region south and west of the islands, and the low energy region to the northwest.

The GEOSAT results from the earlier time period are similar in many respects to the T/P and ERS-1 results, but show significant differences as well. It is not clear whether the differences can be attributed to the lower accuracy of the GEOSAT measurements, or whether they reflect true interannual modulations of the mesoscale energy. Sea surface heights from an eddy-resolving numerical model were evaluated in an attempt to answer this question, but it was found that the quality of the numerical model heights is very questionable. Comparisons to mesoscale energy estimates from XBT-derived dynamic height variability show that the altimetric analyses are more reliable. We are presently in the process of obtaining output from a different type of numerical model to further study the cause of the interannual differences in the mesoscale energy fields.

Work in progress is focused on developing analogous statistical descriptions of the fish catch from the logbook data in order to quantify relationships between the mesoscale variability and the fisheries. These results are expected to be available by the summer of 1996. In the spring we will also begin work on the second phase of our project which will expand on our statistical descriptions by attempting to evaluate the relationship of fish catch to specific mesoscale events that are observed by the altimeters.

Hawaii-Based Swordfish Longline Vessel Distribution and Catch from 1991 to 1994: Relation to Observed Thermal Structure and Lunar Periodicity

Keith A. Bigelow[1] and Christofer H. Boggs[2]

[1]Joint Institute for Marine and Atmospheric Research
National Marine Fisheries Service/Honolulu Lab

[2]NOAA/Southwest Fisheries Science Center
National Marine Fisheries Service/Honolulu Lab

A major requirement for improving the assessment of the swordfish resource exploited by the Hawaii-based longline fishery is to evaluate the environmental influences affecting the availability and catchability of the resource. We compare longline catch and effort data with thermal structure and lunar information to examine how these environmental factors influence effort distribution and fishery performance.

Commercial longline fishermen may target swordfish, tuna or a mix of species depending on the changing availability and marketability of the resources. Cluster analysis was used to quantitatively classify longline set types based on catch composition. Our analysis was restricted to a 4-year time series of 22,258 longline sets classified as swordfish sets.

Swordfish longline effort is significantly autocorrelated on lunar and seasonal scales. Corresponding catch per unit effort (CPUE) estimates were also autocorrelated on a lunar scale for swordfish and other pelagic species. Cross-correlation analyses between CPUE and moon phase time series identified that CPUE was coherent with the moon phase at short time lags (<3 days) for most species; thus, higher CPUE was associated with full moon events.

A computer animation of spatio-temporal fleet distribution and CPUE with contemporaneous sea surface temperature (SST) data derived from Advanced Very High Resolution Radiometer (AVHRR) satellite measurements is presented. Distribution of effort and SST was bimodal, with modes occurring at 18°C and 4°C. The bimodal SST preference is related to seasonal isotherm movements through the fishery. The 18°C mode is largely composed of effort concentrated at the subtropical front (27°N-32°N) during winter and spring. The 24°C mode is composed of effort scattered north of the Hawaiian Archipelago in summer and early fall. Throughout the year, higher CPUE occurs more frequently in longline sets fishing in cooler water (<20°C), which may indicate a preferred temperature habitat. Within each year, the highest CPUE occurs when surface isotherms are concentrated and there is little latitudinal isotherm movement with time, which corresponds to March and September when surface isotherms reach their most southern and northern latitudes. Although SST may be an important factor influencing the geographic range of swordfish, estimation of SST fronts or gradients may be more important in evaluating and modeling the dynamic relationship between longline catch and effort.

Relationship Between Tuna and Environment: A Model to Explain the Distribution of Skipjack Tuna in the Tropical Pacific Ocean

Patrick Lehodey

Oceanic Fisheries Program
South Pacific Commission
Nouméa, New Caledonia

During the past decade, the catch of surface tuna fisheries in the tropical western Pacific ocean increased drastically with the development of purse-seine fishing. Despite this increase, skipjack tuna, *Katsuwonus pelamis*, which is the major component of the catches in this region, appears to be exploited at a low to moderate level. Thus, one of the most (if not the most) productive tuna stocks in the world occurs in a region of the ocean generally considered to have low biological productivity, especially in comparison with the eastern Pacific. This situation appears all the more paradoxical since tuna, particularly skipjack which have very high energy requirements, feed only on epipelagic prey.

This paper analyzes the distribution of skipjack tuna catches in the western Pacific ocean along with the major oceanographic features (temperature, depth of the thermocline, oxygen) known to influence the movements and the distributions of tuna. Although these features define the habitat of tuna in three-dimensional space and time, they do not seem to be sufficient to predict the distribution of skipjack tuna within this habitat. The hypothesis that the presence of food is the major factor explaining distribution of tuna within the limits of their habitat was investigated using a general transport model based on the advection-diffusion equation to simulate the redistribution of the original (primary) productivity by oceanic currents. Despite the simplicity of the model and the limitation of the data, the results provide a plausible explanation for the distribution of skipjack in the two major surface fishing zones of the Pacific exploited by purse seiners. The model also explains the paradox of high skipjack concentration in waters of low primary productivity in the western Pacific.

Prospects for Development of Fully Integrated Models for Pelagic Fishery Management

John R. Sibert

Joint Institute for Marine and Atmospheric Research
University of Hawaii at Manoa

The assertion that it is necessary to be able to forecast catch in order to be able to develop optimal policies is the basis for the development of fully integrated fisheries models. This assertion is derived both from observation of the policy development process and from analysis of fisheries systems. Fishery management is the attempt to manipulate one component of the fishery system to achieve a prescribed goal. Fishery systems consist of several coupled and incompletely understood subsystems. For instance, the *productivity* of the resource is a biological phenomenon that depends on the dynamics of the species under exploitation and on constraints imposed by the environment. The *exploitation* of the resource is a social phenomenon that depends on economic and cultural forces that may be both local and global in scope. The *act of exploitation* couples natural production systems to human social systems and introduces new areas of research. The PFRP supports research projects that investigates components of these coupled systems. A goal of "integrative" modeling is to attempt to provide theoretical coupling between model subsystems.

Analysis of the distribution in time and space of fisheries resources and fishing fleets is the chosen starting point for the development of coupled models. Models of tuna movement based on the well known "advection-diffusion" model have been developed that predict time and place of recapture of tagged tuna with reasonable accuracy. These predictions depend strongly on knowledge of the distribution of conventional measures of fishing effort. Deficiencies in the current model are consequences of the choice of parameterization, lack of fundamental knowledge of aspects of tuna population dynamics, and the general disability to forecast fishing activity.

New models are under development that will incorporate more "biological" parameterizations of movement. Further research is required to address tuna population dynamics and to create a socioeconomic basis for computing the distribution and intensity of fishing.

Design of Tag-Recapture Experiments For Estimating Yellowfin Tuna Stock Dynamics, Movement and Fishery Interactions

Peter J. Bills and John R. Sibert

Joint Institute for Marine and Atmospheric Research
University of Hawaii at Manoa

Hypotheses have been developed for the release site, natural mortality and movement of tagged yellowfin tuna in the Hawaiian Islands. Since the paths taken by released individuals are unknown, the movement parameters that can be determined from tag release-recapture experiments are limited to those of bulk movement, assumed to have both directed and random components. Adopting this viewpoint allows the application of the advection-diffusion mathematical model to the release-recapture data; the "advection" parameter is interpreted as the component of "directed movement" in a given region and the "diffusion" parameter as the component of "random movement."

NMFS (Honolulu) has supplied monthly averaged fishing effort and catch data for longline, troll and handline fleets operating near and among the Hawaiian Islands based on 1991 and 1992 logbook reports. From this data we have calculated relative catchability coefficients, viz. simple ratios of effort to catch, the actual population of yellowfin being unknown. Thus, monthly recapture distributions using the reported effort data of the fleets can be estimated. From the recapture information the movement and relative catchability parameters can be estimated, as well as the value of natural mortality set under a chosen hypothesis.

In order to determine the reliability of the parameter values so determined, we can alternatively regard the predicted number of recaptures in one month in a given cell of the model as a random variable and run a great number of simulations wherein the estimated number of recaptures follows some specified probability distribution. The Poisson distribution is chosen because it is commonly used to estimate the probability of a "rare event" such as the recapture of a tagged tuna from a large population of tuna, most of which are not tagged. Such a procedure for determining the reliability of parameter estimates is termed a Monte Carlo process.

Two release sites frequently visited by fishers and abundant in yellowfin are chosen: Cross seamount and the Moloka'i/Maui region northwest of Hawai'i -- these will be referred to as the Cross and Hawai'i release sites. Estimates of the effectiveness of parameter recoveries for each hypothesis are presented and show that the best strategy involves releases at both sites. The swordfish longline fishery catches very few tags under the chosen hypotheses.

The influences of a number of other factors linked with the parameter estimation have also been examined. The finite difference scheme originally used to solve the advection-diffusion equation uses upwind differencing for the advection terms but centred-space differencing gives more accurate results within certain physical constraints that appear to be naturally obeyed by species such as skipjack and yellowfin tuna.

The effect of using open or closed boundaries around the model domain is also tested. In a basin as vast as the Pacific it is reasonable to place open boundaries around a model of the Hawaiian islands, but how does this affect parameter estimates, particularly the estimate for natural mortality?

Laboratory and Field Research to Enhance Understanding of Tuna Movements and Distribution, and to Improve Stock Assessment Models

Richard W. Brill

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Significant amounts of biological data (e.g., age and growth, reproduction, dispersal, etc.) are involved in tuna population assessment models. Although it is well known that oceanographic conditions can significantly affect the vulnerability of tunas to different types of fishing gear, most models rely heavily on catch-per-unit effort data (CPUE) and assume a constant vulnerability to specific types of gear. As a result, current models often can not readily differentiate human (i.e., fishing mortality) and environmental influences on the continually changing apparent abundance of tunas. Effective fishery management policy is likewise dependent upon the ability to differentiate changes in stock size from changes in gear vulnerability. There is general consensus that temperature, ambient oxygen, and prey abundance are the main factors determining the horizontal and vertical movements, available habitat and gear vulnerability of tunas. The specifics of how these factors act and interact are, however, not well understood. It is the overall objective of this project to use laboratory and field (telemetry) studies to establish direct links between environmental conditions, fish movements, distribution, and gear vulnerability and thus provide a direct means of improving current tuna stock assessment methods.

Two laboratory studies have so far been completed. The first was designed to measure the primary and secondary circulatory volumes of yellowfin tuna. These data will be needed to design future experiments that will include the injection of specific quantities of vasoactive drugs. The technique employed involved injection of known quantities of radioactive (Cr51 labeled) red blood cells and dye-labeled dextrans. The former remain in the primary circulatory system whereas the latter distribute in both the primary and secondary circulatory systems. The data show that, like other fishes, the volume of the primary circulatory system in tunas is approximately 50 ml/kg (i.e., 5% of body weight). The volume of the secondary circulation in yellowfin tuna (approximately 20 ml/kg or 2% of body weight) is, however, smaller than that reported for other teleosts. The second completed laboratory study was designed to assess the effects of open and closed system temperature changes on the acid-base status of skipjack tuna blood in vitro. These data complement already published data from yellowfin tuna and are primarily needed to interpret the blood acid-base changes and resultant cardio-respiratory function changes seen in fish exposed to rapid ambient temperature changes. Preliminary analysis of the data indicates plasma bicarbonate levels tend to be higher in skipjack tuna than yellowfin tuna and that the effect of open system temperature on plasma pH and bicarbonate is greater in skipjack tuna blood than in yellowfin tuna blood. The reasons for these differences, however, remain unexplained.

Two ultrasonic telemetry studies in which I directly participated are also nearing completion. The objective of ultrasonic telemetry is to acquire data that can be used to test laboratory generated hypotheses about the effects of oceanographic conditions on the movements and distribution of tunas. The first project was conducted off the southern California coast and was led by Dr. Barbara Block (Hopkins Marine Station, Stanford University). The second was conducted off the Kona coast of the Island of Hawaii and was led by Dr. Chris Boggs (NMFS, Honolulu Laboratory). The former targeted small (5-10 kg) fish at the northern-most edge of their range. The latter targeted large (75-100 kg) fish. Off southern California, yellowfin spent approximately 80% of their time above 40 m and in waters warmer than 18° C. This behavior is similar to that seen in equivalent size yellowfin tuna tracked near the Hawaiian Islands, in that in both areas the fish spent the majority of their time in the warmest waters available. Surprisingly, the large yellowfin tracked off the Kona coast showed behaviors strikingly similar to that seen in 3-6 kg fish tracked near Hawaii. In both cases the fish spent the vast majority of their time in the upper uniform temperature layer (shallower than 100 m). Large yellowfin tuna, therefore, apparently do not use their slower rates of heat exchange to take advantage of food resources available at greater depths (i.e., at colder water temperatures). Large yellowfin tuna also regularly visited fish aggregation devices (FADs) as do the smaller fish. Behavior patterns in yellowfin tuna, therefore, appear fixed. In other words, the tracking data imply there are no major shifts in behavior patterns as yellowfin tuna grow.

A Regional Simulation Model for Western Pacific Tuna Fisheries

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The tuna fisheries of the western tropical Pacific are among the most valuable in the world. They have experienced rapid expansion in recent years, mostly due to the development of the purse seine fishery which in 1994 accounted for 65% of skipjack catches and 50% of yellowfin catches. Approximately half of the total skipjack and yellowfin catches are made inside the EEZs of western Pacific island nations. It has, therefore, become important for those countries to receive advice on the optimal number of licenses of purse seiners and other vessel types that should be allocated every year.

We are addressing this need by developing a bioeconomic simulation model of the western Pacific tuna fishery. The biological component of the model will estimate the catch by species and by gear under different effort regimes. This model needs to incorporate several characteristics of the fishery. It is a multi-species fishery targeting mainly yellowfin, skipjack and bigeye with potential interaction between various fleets (purse seiners, pole-and-line and longline vessels under several flags). Consequently, the model must deal with the three species and the range of gears/fleets that targets them.

Tropical tunas have developed geographical distribution and spatial structure needs to be included in the model to account for the fishing effort distribution and the movements of fish. To be realistic, the model must also permit variation in gear selectivity with fish age or size and take into account the growth of fish which can be done by including an underlying age structure to the fish population. Ultimately, information on the costs of effort, price of fish and the means by which island countries derive economic benefit from the fishery (mainly as payments) will be included so that the economic impact of different effort regimes can be explored.

Some preliminary results of the biological component of the model are presented using a very simple parameterization. One species (skipjack) is exploited by the fleets (six purse seine and two pole-and-line fleets). Movements of the fish, described by an advection-diffusion equation, are mainly directed by average monthly sea surface currents. Average monthly fishing effort distribution over the period 1991-1993 was used. Recruitment, occurring every month, is assumed to be constant throughout the year. Recruitment levels and catchability are scaled so that the model accurately predicts the average yearly catch by fleet observed during the period 1991-1993.

To see the impact of the development of the purse seine fleets on the pole-and-line catch, reproduced on a larger spatial scale, an analysis is already being conducted by Sibert et al. (1995). The simulation is started with no purse-seine fishing effort and run with regular increments representing 20 of the averaged 1991-1993 purse seine fishing efforts. Between each increment, the population and catches are allowed to re-equilibrate. The results show the impact of incorporating age structure into the model. The impact of the purse seine fishery on the pole-and-line fishery is found to be stronger than that found when the size/age of the catch is ignored. This is due to the decrease in average weight of fish in the catch when the fishing mortalities increase: a larger total number of fish are caught by the fleets but their size (and consequently their weight) is smaller.

Distributions of the fish obtained using only sea surface currents as the directed movement component appear to be unrealistic: large concentrations of fish occur in areas where no fishery has ever operated and areas where almost no fish are heavily exploited. Obviously, other parameters need to be incorporated into the movement and recruitment processes so that more realistic distributions of the populations are obtained. Sea surface temperature and availability of food are both possible candidates. At the other end of the fishery system, using constant distributions of fishing effort is also unsatisfactory. The fishermen react to their environment and this reaction, or behavior, needs to be taken into account. This means that some behavioral model of vessel movement should ideally be incorporated. This task, along with the estimation of price and cost parameters is currently underway with the cooperation of economists at the University of Queensland.

Tagging Program for Seamount Yellowfin and Bigeye Tuna

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This project evolved from requests made to the WPRFMC by fishermen participating in the hybrid troll/bait fishery for yellowfin and bigeye tuna which is primarily focused on the seamounts and weather buoys located south of Hawaii. Early participants in the fishery became concerned that it was being over exploited by more recently arriving boats and wanted information concerning the residence times and dispersal patterns of seamount associated fish.

This project took considerable time to get off the ground due, in part, to the university structure being unused to the types of activities associated with pelagic fisheries field work, especially that which utilizes non-employee fishermen and their vessels, which requires our technician to work off of regular fishing boats, and which also requires the use of recapture rewards made to the general fishing public. While not strictly a "result" in the typical scientific sense, the learning that has occurred during this start-up phase may be of use to others contemplating these types of activities under the auspices of a public university.

All the requisite procedures and personnel are now in place but logistical, biological and ocean conditions have been extremely uncooperative for the past several months. Not only have several potential collaborating fishing vessels broken down, but fishing has been very slow at the seamounts while being unseasonably very good closer to shore. Also, the weather on the target fishing grounds has been bad for several weeks. These factors have reduced the fishing effort in the target area to almost zero. However, the weather has made its transition from summer to winter patterns and, if previous seasons are any indication, the seamount fishery will quickly expand and we expect to greatly increase the productivity of the tagging program in the next few weeks.

To date, 48 bigeye and 11 yellowfin tuna (2.3 to 6.8 kg) have been tagged and released at Cross Seamount. Two of each species have been recovered with times at liberty ranging between 4 and 44 days. All fish were recaptured at the point of release (Cross Seamount).

A Pop-Up Satellite Transmitting Archival Tag (PSTAT) for Studying Swordfish Movement and Behavior

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Collecting quality data on the migration patterns and spatial dynamics of large pelagic fishes is often very difficult. Even large-scale conventional tagging experiments are often hampered by low recapture rates, and by release and recapture locales restricted to areas in which commercial fisheries operate, resulting in an inadequate picture of stock distribution and spatial dynamics. In addition, conventional tags provide no information on diving behavior, preferred depth and water temperature or, more importantly, how an individual moves between the points of release and recapture. While ultrasonic telemetry has provided invaluable data on the behavior and physiology of many large pelagics, these data have predominantly been collected over periods of hours to a few days and thus are of limited use in describing and understanding large-scale movement patterns or medium-to-long-term variation in behavior.

The recent development of archival tags and their use on southern bluefin tuna (SBT) provides a new tool for studying movement, behavior and physiology over long periods. In the case of SBT, despite decades of conventional tagging and intensive ultrasonic tracking, archival tags are providing new and important insights into the species and the fisheries that exploit it. The power of archival tag technology to collect data over many years on a broad range of parameters critical to our understanding a species' spatial dynamics suggests that in the future it will be useful for many of the large pelagics.

However, for species such as the marlins and swordfish, in which recapture rates are likely to be very low, the high cost of archival tags is a major deterrent to their use. Recognizing this, but also recognizing the urgent need for data on the movement of swordfish in the Central Pacific, we are developing a hybrid archival and satellite transmitting tag. This tag will employ proven technology that is currently in use for other applications: an archival system to collect data and control the tag functions and a PTT to transmit data stored in the archival tag memory to System ARGOS carried by the NOAA satellites. Integration of these two major hardware components with smart software and a mechanism to release the tag from a fish at a predetermined time provides a system that will allow us to collect data from every fish we tag. Each tag will be significantly more expensive than an archival tag, but the recovery rate will no longer be a concern.

The presentation will provide a brief outline of the data being collected on SBT using the current generation of archival tags. The PSTAT design will then be described and discussed in relation to the planned research on Hawaiian swordfish.

Hawaii Fleet Industry and Vessel Economics Project

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The Hawaii Fleet Industry and Vessel Economics project (HIFIVE) is a three-year project comprised of seven sub-projects emphasizing different aspects of economic research on Hawaii's commercial fishery for pelagics (primarily tuna, swordfish, blue and striped marlin, mahimahi and ono). The pelagic fisheries under consideration by the HIFIVE project include the following domestic commercial fishing fleets based in Hawaii: longline, commercial troll and handline, and charter-boats, as well as some research on the markets associated with these fleets. The HIFIVE principle investigator also collaborates formally with the University or Hawaii's Department of Agricultural & Resource Economics (AREC) project on a multi-level, multi-objective programming model of Hawaii's pelagic fisheries. HIFIVE researchers will also be involved in forthcoming two projects: "The economics of the recreational fishery for pelagics in Hawaii," and "The economic interactions between U.S. longline fisheries."

The first year of the HIFIVE project (1994-5) concentrated on the Hawaii longline fishery. A number of integrated and summarized data bases were constructed for economic analysis purposes. A survey of longline costs and operations information was completed by the JIMAR researchers, and a cost-earnings analysis completed, with earnings data generated by merging NMFS longline logbook information with Hawaii Division of Aquatic Resources commercial catch reports. Substantial progress has also been made on analysis of institution, production, and market relations concerning the Hawaii longline fishery.

The second year project (1995-6) will extend the economic analysis of the Hawaii longline fishery and collect economic information on the small-boat commercial pelagic fisheries in Hawaii.

The third year of the project (1996) will emphasize modeling of the longline fleet's activity.

Hawaii Pelagic Market Channels and Cointegration Analysis

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This project is part of the Hawaii Fleet Industry and Vessel Economics project (HIFIVE). Its objectives include description of the major market channels used by pelagic fishermen and seafood dealers in Hawaii as well as the use of cointegration analysis of market dynamics. The market channels component will utilize existing information from Hawaii seafood auctions, dealers, and brokers to estimate the flow of pelagic fish through the Hawaii market, including "exports" and "imports" from Hawaii. Cointegration analysis involves a time-series technique which examines the lag structure of apparently independent processes to identify their dynamic (and integrated) components. This analysis will be applied to longline and troll-handline data from Hawaii. Activity in this component of the HIFIVE project is planned for mid-1996.

Fishing Power, Harvest Capacity, and Fishing Effort: An Economic Analysis of Catch Rates in Hawaii's Longline Swordfish Fishery

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Although foreign longliners have been landing swordfish in the Pacific for decades and U.S. longliners have done likewise in the Atlantic, the targeting of swordfish in the Pacific by domestic longliners is a relatively new phenomenon. Since 1989, the swordfish fishery has been the main source of growth, landings, and revenue in the Hawaii longline industry. This growth prompted the attention of non-longline fishers and thus regional management authorities. Even though the longline industry has faced increased regulation, it has continued to prosper. However, that trend was reversed in 1994 as swordfish landings and revenue decreased sharply and many vessels either altered their fishing strategy or left the Hawaii fishery. Little economic research has been conducted with respect to modeling and explaining the behavior and performance of the Hawaii longline fleet. The dramatic changes in the longline industry and lack of previous research are the main motivations behind the current study.

An additional motivation for the current study lies with the theoretical and applied meanings of certain terms within fisheries science. The terms in question are fishing effort, fishing power, and harvest capacity. It is uncontroverted that these terms are sometimes used interchangeably and at other times meant to represent or measure entirely different factors. This terminology problem is akin to the differential use of the term "efficiency" within economics. As in that case, the problem is primarily due to the use of different methodological approaches as researchers from different paradigms or different fields attempt to analyze the same outcomes. Although research from alternative fields of study should be complementary, that is a difficult, if not impossible, goal to achieve if different "languages" are being used. This study is partly meant to address this problem as well.

In this study, fishing power represents the ability of a "vessel" to catch fish -- swordfish in this case. The theoretical model views fishing as a production process. As such, fishing is made up of different components and, more importantly, occurs over time. To capture this aspect of fishing, the chosen unit of analysis is a fishing trip. A trip has a somewhat definable beginning and end with various fishing events occurring between those points in time. Given the longline fishing method, catch is measured in terms of number of fish rather than pounds. Therefore, the study attempts to determine which factors explain the variation in swordfish catch across longline trips. In other words, what are the factors which augment, diminish, and/or constrain a vessel's ability to catch swordfish? Data for the study came from the NMFS logbook data base (which includes trip data from December 1990 through 1994), the Vessel Economics cost-earnings survey data base, and the NMFS permit applications data base.

Given the types of factors which need to be taken into account, an analysis of covariance with interaction effects regression model is employed. Descriptive statistics, simple correlation analysis, and anecdotal evidence suggested which factors to include in the full model. However, the full model's results were contrary to some of the preliminary and expected findings. The full model has significant explanatory model as the R^2 and adjusted R^2 are .873 and .762, respectively. As anticipated, the ability to catch swordfish is a complex phenomenon and, thus, so is the model. However, the factors which determine a vessel's fishing power fall into five general categories: 1) the fisher's behavior/fishing strategy, 2) the behavior of swordfish, 3) the behavior of other fishers, 4) vessel/operator characteristics, and 5) the behavior/existence of other species. The model's results indicate that factors in the first two categories are the most important with respect to fishing power. Two cautionary statements with respect to the findings are important. First, the analysis is conducted at the trip level; therefore, different relationships would be expected if the analysis were conducted at the set or vessel level. Second, the model assumes that the nature of the economic relationships does not vary over the time period analyzed. If this assumption is not plausible, the model must be adjusted to take such effects into account.

Cost-Earnings Analysis of the Hawaii-Based Domestic Longline Fleet

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Fishery management has historically emphasized biological concerns, however the maximization of fishery benefits to society also requires an explicit concern for the socioeconomic condition of fishery participants. In order to discover the most economically efficient methods of fishing and fishery management, data on fleet costs and earnings are vital.

The 1993 Hawaii longline fleet consisted of 167 permitted vessels, of which 122 were active. Interviews were conducted with the captains and/or owners of 102 of these vessels. A specially designed survey was used for these interviews, the majority of which were conducted in person at the docks. The survey focused on the costs of the average trip by each vessel in 1993, as well as the fixed costs for that year. A total of 95 useable vessel-level responses was obtained. Revenue information was extracted from local seafood dealer reports as well as from a linked state and federal database which provided catch and revenue information on a per-trip basis.

On average, vessels covered their trip costs plus a portion of their fixed costs with each trip and made enough trips in 1993 to realize an annual net profit. Some groups of vessels did better than others: those that targeted swordfish averaged an annual net profit of $11,075; those that targeted tuna averaged an annual profit of $20,486; while those which had a targeting strategy they called "catch whatever you can" (or mixed), averaged an annual net profit of $47,439. These differences were found to be primarily driven by differences in fixed costs relative to revenue earned.

Within these groups, there was substantial variation. The annual net profit for swordfish vessels ranged from -$218,563 to $226,961 with its median at $6,960. For tuna vessels the rate was from -$90,704 to $253,303 with a median of $16,212. The annual net profit for mixed target vessels ranged from -$82,621 to $146,901, the median value for this group was $53,735.

The longline fleet was found to be operating at between 70% and 80% of its maximum capacity, as calculated using average trip lengths and turnaround times. All groups could improve their profitability by fishing at maximum capacity (given unchanged catch rates and prices), but the increase would be least for vessels which target swordfish due to their relatively long average trip length (31.35 days compared to 13.56 days for tuna vessels and 18.52 days for mixed vessels) which limits the number of trips that can be made in a year.

Because variable costs as a percentage of total revenue did not vary substantially between groups, an implication of this study is that overcapitalization may exist in the Hawaii longline fishery. Fixed costs are dominated by depreciation and maintenance charges, as well as insurance and loan payments -- all of which are influenced by vessel size and value. A portion of the 1993 fleet was unable to earn enough revenue to cover its fixed costs and thus did not realize positive returns. However, there may be other reasons for presence of these vessels in the fishery.

An earlier version of this paper was presented at the 46th Annual Tuna Conference.

Longline Technology and Regulatory Policy in Hawaii

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This paper develops a supply response model of the Hawaii longline fishery to determine the effects of regulatory policy on longline operations. A supply response model utilizes a multi-product revenue function which relates revenue (per trip) to the expected market returns for individual species (per unit effort), the actual market prices of the species, and a fixed input specific to the harvesting vessel (i.e., length overall).

Information on technical interactions is determined by the separability of the production functions (i.e., lack of cross price effects between species). Information on economic interactions is determined by price output elasticities.

Preliminary results suggest that smaller vessels are more price responsive than larger vessels, especially in terms of selective targeting (substitutability). Larger vessels, however, are more responsive in trip behavior in terms of the price of their primary target species.

The implications are that longline vessels appear to be able to substitute other species for yellowfin, and, as such, if given a zero quota for yellowfin landings, could be allowed within the area closures (in terms of catch competition).

Cost-Earnings Analysis of Hawaii's Commercial Troll and Handline Fisheries

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There are approximately 500 commercial troll-handline pelagic fishing vessels in Hawaii, although their characteristics are not well known. A summary of catch reports submitted for 1994 reveals that these vessels reported a total pelagic catch of over 5 million pounds and gross sales revenue attributed to pelagic species of $10 million. This project will collect detailed cost information concerning the operations of these vessels through both direct and indirect surveys. Such information will provide an understanding of the present scope and scale of operations as well as a basis for evaluating the potential effect of management decisions.

A Multilevel and Multiobjective Programming Model of Hawaii Commercial Fisheries

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Progress was reported on two components of the project: (i) the identification and definition of fisheries management objectives, and (ii) multiobjective model of the Hawaiian fishery. Under the first objective, a comprehensive list of objectives used in the Council's decision-making process has been prepared. Interviews with selected members of Council sub-committees have been conducted. A survey has been sent out to obtain rankings of the various objectives from members not based in Hawaii. A trial session to elicit rankings through an interactive procedure (using the Analytic Hierarchy Process) was also conducted with the NMFS staff. Under the second objective, the NMFS linear programming model is being expanded to include multiple objectives. An example with two conflicting objectives -- maximizing recreational catch and fleet profits -- that reveals the trade-off frontier was shown. Further extension of the NMFS model to include other important objectives is in progress.

Quality and Product Differentiation as Price Determinants in the Marketing of Fresh Pacific Tuna and Marlin

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A. Major Findings:

Fresh tuna is highly differentiated in product types and associated market niches. Fresh marlin is less differentiated. The wide variation in fresh tuna prices corresponds with varying quality requirements of highly differentiated end uses. Through quality grading, tuna acquire individual identities that can be correlated with market prices. Premium products command higher prices than "low end" quality products.

Tuna grades integrate effects on fish quality of fishing, handling and storage. Quality grades define market and price interactions among tuna from multiple sources and fishing gear types. The market trend is toward even greater differentiation in product types and associated quality requirements.

B. Fishery Management Implications:

Without consideration of tuna quality grades, market conditions and price trends may be misinterpreted. Tuna market competition in Hawaii and elsewhere is not based narrowly on gear type, but more broadly on quality, or tuna grades.

Pacific island fresh tuna harvesters are well aware of market conditions and price fluctuations, but important quality information is not always communicated back to them. The proportion of premium grade tuna products in landings by Pacific island tuna fishermen could be improved through better quality control.

Some apparent opportunities for fresh tuna export are not being fully exploited by Pacific island suppliers. Greater diversity in products would add value to island-based tuna fisheries.

Tuna that are landed fresh should be clearly distinguished from frozen tuna landings in U.S. Commercial fishery statistics.

The Contribution of Tuna Fishing, Transshipment and Processing to the Economies of American Samoa, Commonwealth of the Northern Marianas and Guam

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American Samoa, Commonwealth of the Northern Mariana Islands, and Guam have derived economic benefit from tuna fishing in the Pacific Islands region for many years. American Samoa has been the home to the two largest tuna canneries in the Pacific and has been a major fueling and provisioning base for fleets that supply StarKist and Samoa Packing processing plants since the 1950s and 1960s. In the Commonwealth of the Northern Mariana Islands, Tinian has been a transshipment port for tuna vessels supplying processors, primarily in East and Southeast Asia, since the 1970s. Guam has been a major transshipment point for sashimi-grade tuna for the Japanese market caught by Japanese, Taiwanese, and Korean longline vessels since the mid-1980s.

The increasing competitiveness of fleet operations, transshipment, processing and changes in access agreement provisions in Forum Fishery Agency member countries has created a great deal of uncertainty about the future of the tuna industries in all three jurisdictions. The number of longline fishing boats operating in the Federated States of Micronesia (FSM), the Republic of the Marshall Islands (RMI), and Palau increased from an estimated 296 vessels in 1990 to an estimated 711 in 1994. Sashimi-grade tuna export operations were established in FSM, RMI, and Palau with fish flown to Guam and Saipan and transshipped onto jumbo jets bound for Japan. In 1993, the Federated States of Micronesia began requiring that tuna caught in their waters be landed in their ports as a provision of licensing agreements for foreign fleets. On Guam the FSM land-locally policy and the development of the air transshipment operation through Guam were seen as direct threats to businesses transshipping tuna through the port of Guam.

In 1993, the number of purse seiners transshipping cannery-bound tuna through Tinian began to decline. The "Z-boat" fleet, which made up the majority of boats calling at Tinian, was reportedly moving to Madang in Papua New Guinea where one of the Zuanich family, who owns that fleet, entered into an agreement with the government to build a tuna processing plant. Agents on Tinian were predicting that the operation on Tinian would be shut down by the end of 1993, but this did not happen. The number of "Z-boat" port calls continued to decline from 20 in 1993 to 2 in 1994, but, the number of Taiwanese seiners increased. Still, this did not offset the overall decline in transshipment from a high of 72,405 tons in 1991 to 19,782 in 1994. In 1995 a new cannery-grade tuna transshipment operation was established on Guam with fish being off-loaded directly into freezer containers at a cost significantly lower than traditional transshipment operations like the one on Tinian. How this will affect the Tinian operation is very uncertain.

For many years, StarKist Seafoods has been pressured to reduce operating costs of its American Samoa cannery to compete more effectively with foreign processors. In minimum wage hearings and negotiations for tax exemption certificates, StarKist has threatened to close its Samoa packing plant unless costs could be contained. In 1994, StarKist Samoa suffered a number of financial setbacks that appeared to seriously threaten the future viability of StarKist Samoa. While StarKist has reportedly decided to remain in Samoa, its fleet of twelve seiners began bunkering off-shore in March 1995 in order to cut costs. This resulted in a 50% decline in fuel sales and excise tax collected by the territorial government.

Tuna operations in American Samoa, Commonwealth of the Northern Marianas and Guam contributed to those economies in very different ways and to different degrees. In American Samoa, the canneries employ about 4,000 workers that receive about $27 million per year in wages. The canneries purchase about $8 million in water and electricity. In 1993 and 1994, the fleets spent between $58.3 and $78.7 million per year on goods and services, and, until this year, paid about $1 million in fuel taxes.

In the Commonwealth, the situation has been quite different. The Tinian transshipment operation has employed about 40 local workers and about 70 guest workers with wages totaling about $600,000. Total expenditures by the boats calling at Tinian were about $1.4 million in 1993. Most of the boats calling at Tinian refuel in Guam and buy most of their provisions there. The air transshipment operation in Saipan had ten local employees in 1994 and gross receipts of the transshipment agent were between $300,000 to $400,000, significantly less than the total expenditures by the boats calling at Tinian.

On Guam, the purse seine fleets calling at Guam spent between $50.8 million and $102.3 million on fuel, provisions and services in 1994. The longline fleets spent between $14.4. million and $19.8 million during the same year, and the longline transshipment operation employed about 130 people. The transshipment of tuna through Guam airport resulted in little or no additional employment and a marginal amount on fuel sales to aircraft. The new freezer container transshipment operation, which is very new, has resulted in additional employment and appears to be attracting additional vessels to Guam which will add to the economic benefits of refueling and provisioning operations in the port.

This study has shown that it is possible to estimate the contribution of tuna operations to the economies of American Samoa, Commonwealth of the Northern Mariana Islands, and Guam from data available from existing sources. Because of differences in estimated expenditures by vessels calling at ports in the territories and Commonwealth, those estimates must, by necessity, be presented as ranges of estimates. Even ranges of estimated expenditures provide the governments and the Western Pacific Regional Fisheries Management Council some sense of the importance of these industries to their economies.

Providing such estimates for a single year or even providing information on trends in the number of port calls or volume of fish transshipped provides little understanding of the complexity and fluidity of the tuna industries in the American Flag Pacific Islands. Indeed, one of the problems encountered by the researchers involved in this study is that the situation in all three jurisdictions has been so fluid; it has been very difficult to provide the governments with any guidance on how they can gain greater benefits from tuna processing, transshipment, and homeporting. We hope, however, we have identified some of the important sources of economic benefit, and the kinds of changes in the industries that the governments and the Council will have to monitor in order to anticipate increases or decreases in economic benefits in the future.

Economics of Recreational Fishing for Pelagics in Hawaii

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This project (1996) will enable researchers to describe the economic gains or losses resulting from potential changes in the availability of pelagics to small boat anglers. The project focuses on the behavior and values of individual anglers and will not be a systematic effort to estimate total catch and effort by these anglers.

The objectives of the research are: to estimate the marginal economic value of catching important pelagic species by small boat anglers in the marine recreational sector of the main Hawaiian Islands; to model and estimate the behavior that leads to this economic value; to develop an empirical basis for understanding the substitution between pelagics and other fish sought by small boat anglers; and to obtain a good intuitive assessment of the magnitude of the aggregate economic value of small boat fishing by sports anglers.

The issue of "defining" the term *recreational* in the small boat fishery in Hawaii is difficult, and this project will compile information on both commercial, non-market, and recreational behavior as part of this task.

The project is planned for three years, with year 1 (1996) involving methodological development and survey planning, year 2 involving the survey, and year 3 involving econometric analysis of survey data and writing up the results.

Economic Interactions Between United States Longline Fisheries

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As the project's title suggests, the authors believe that the various U.S. longline fisheries are economically interdependent. As such, a change in the economic health of one longline fishery can impact any or all of the other longline fisheries. Such an impact would occur as vessels exit declining fisheries and enter expanding fisheries. The entry and exit of vessels can cause dramatic changes in each fishery's fleet size and thereby reallocate economic resources and competition. As a longline fleet expands and competition increases, conflicts over the distribution of fish and the right to fish in particular areas can occur between established longliners, new longliners, recreational fishers, fishers who use other gear, and existing wildlife. Support industries, such as fish dealers and fishing gear suppliers and the local economy, will be positively affected by industry growth. If the industry expands sufficiently, concern over certain fish stocks may also become an issue. As conflicts increase, the responsible government agency(ies) will be asked to allocate fishing rights in the most appropriate manner possible.

If government intervention is likely to be required, then the ability to predict changes in fleet size would be most useful. Therefore, the primary purpose of this project is to determine: 1) what specifically causes a vessel to leave a fishery, and 2) how the vessel owner chooses which fishery to enter. Theoretically, the modeling approach assumes a two-stage decision-making process which is consistent with the nested logit model used in other economic studies of locational choice. First, the vessel owner must evaluate the targeting options available in each fishery. Assuming that vessel owners are utility maximizers, the probability of choosing a particular target, given a particle location, can be estimated by the conditional logit model. Once we know what vessels will do at a particular location, the expected value of fishing in a particular fishery can be estimated for each vessel owner and thus the probability of choosing a particular location.

The migration of vessels between the Atlantic, Gulf of Mexico, West Coast, and Hawaii longline fisheries over the past several years will provide most of the observations for the study. Data will come from the NMFS logbook and shoreside monitoring programs, state catch reports, fishing permit applications, and in-depth personal interviews with vessel owners and operators.

The Hawaii Troll and Handline Fishery: Fishermen's Motivations and Fishing Action

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The motivation of fishermen to engage in fishing can be analyzed in several complementary ways. Rational models examine fishermen's behavior with the assumption that "decisions" are constantly being made. Ritual models assume that fishing situations generate sacred objects, and, ultimately, moral and social solidarity among fishermen. In this report, Hawai`i styles of troll and handline fishing -- holoholo ("recreational"), profit, expense, kaukau ("food"), and combination fishing are discussed. It is argued that Hawai`i fishing is both problematic and consequential. A four-phase model of generic and tournament fishing illustrates that fishing action windows provide opportunities for character management.

Coordinated Sociocultural Investigation of Pelagic Fishermen in American Samoa, Commonwealth of the Northern Mariana Islands and Guam

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The proposed project for American Samoa and CNMI, as well as that being proposed for Guam, will employ an activity system approach that focuses on the individuals involved in various types of fishing activity rather limiting the focus on subsistence, recreational, and commercial fishing.

The primary objectives of the proposed project are to:

- determine the social dimensions of pelagic fishing in the Commonwealth of the Northern Mariana Islands and American Samoa;
- develop social and demographic profiles of fishers in both populations;
- describe activity systems of pelagic fishing in both locations and the relationship of pelagic fishing to other fishing activity and customary social behavior;
- describe contemporary indigenous categories of fishing as they relate to fishing activity and the definitions being contemplated by the National Marine Fisheries Service; and
- assess the potential impact of various management regimes that might be imposed by the governments and the Western Pacific Regional Fishery Management Council on fishing activity.

Field methodologies for the proposed project will be refined and employed in close collaboration with Dr. Don Rubenstein and Dr. Tom Pinhey of the University of Guam (UOG) who are also submitting a separate proposal for funding. In order to ensure compatibility of the methods employed in American Samoa, CNMI and Guam, a planning meeting will be held in Honolulu at the start of the Guam project.

The approach for the proposed project will build upon the project team's field research experience and working relationships with fisheries management officials in American Samoa, Hawaii, Guam and the Commonwealth of the Northern Mariana Islands as reported in: "Justification and Design of Limited Entry Alternatives for the Offshore Fisheries of American Samoa" (Severance and Franco 1988), the "Fisheries" technical paper in the Ocean Resources Management Plan (Hamnett 1991), and "The Contribution of Tuna Fishing and Transshipment in American Samoa, Commonwealth of the Northern Mariana Islands, and Guam" (Pintz and Hamnett 1995). It will also build upon on-going fisheries data gathering and analysis being conducted by the Fish and Wildlife Division of the Department of Natural Resources in CNMI and the Department of Marine and Wildlife Resources in American Samoa.

Tuna Research in French Polynesia, the ECOTAP Program

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ECOTAP is a program planned for a three-year period (1995-1998) to be carried on by EVAAM, IFREMER, ORSTOM; the first two years being spared for experimentations at sea. This program is designed to study the habitat and resources of the tuna targeted by small and medium-sized longliners based in French Polynesia. This relatively new fishery developed rapidly during the past four years, and supplies the local market of fresh tunas at relatively good prices (4 to 8 US $/kg). Total catches reach an estimated 3500 mt for 1995.

The program has two objectives at medium and long term:

1) Improve the fisheries efficiency by providing information on spatial (in EEZ) and seasonal availability of tuna, improve the tactics of line setting, and try to understand, for better use, the behaviour of tuna attracted by FADs. Moored FADs are already commonly used close to main islands by small longliners and artesanal fleet. But if pole-and-line technique is regularly used near FADs in other countries, in French Polynesia, the artisanal fleet makes use of handline to catch tuna between 100 and 200 m depth.

Additionally, use of drifting artificial flotsam could be experimented offshore. Such research relates to ecology and ethology of tunas and focuses to medium-term conclusions. Examples of first results achieved are developed in a joint speech (E. Josse).

2) Assess the local stocks of main species, bigeye, albacore, yellowfin in the EEZ, and compare to the current exploitation rates of the biological stocks at the scale of the Pacific resources. Analyze at the local scale of EEZ the relation between variability of catches and hydroclimatic events such as ENSO. And eventually evaluate the interaction with other fisheries in the South Pacific. This research relates to population dynamics and focuses to medium, then long-term conclusions.

If the exploitation increases, further studies on other species such as swordfish, billfish and other by-catches (kingfish) will be considered from 1998.

Acoustic Tagging and Echo-Survey Together: A New Approach to Study Tuna Behavior

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In the general frame of the research program ECOTAP on behavior and distribution of deep swimming tuna carried on by EVAAM, IFREMER and ORSTOM in French Polynesia, a particular acoustic tagging experiment associated with echo-survey was conducted off Maupiti Island, October 16 - 29, 1995.

A yellowfin tuna (*Thunnus albacares*), 60-cm fork length was caught in the depth (-120 m) close to a moored Fish Aggregating Device (FAD) at midday. The fish was equipped with a sonic tag including a pressure captor and was tracked during 24 hours.

During the tracking, several successive behaviors were observed, affecting horizontal and vertical movements:

- a behavior of association with the FAD in the depth (-150 m) just after the tagging;
- a phase of free swimming directed offshore and in the depth (-200 , -300 m) until the sunset;
- a progressive return to the FAD swimming in shallower layer (0, -150 m) during the first part of the night;
- a free swimming phase, shallow (less than 50 m generally) around the island of Maupiti during the second part of the night;
- an association close to the surface (less than 5 m) with the ship, by the end of the night and during the morning. It allowed to drive back the fish to the FAD;
- as soon as close to the FAD, a new association behavior with the FAD in the depth (100, 230 m).

The biological environment in which the yellowfin tuna swims has been observed during the whole tracking using a scientific echo-sounder SIMRAD EK500. Two deep scattering layers were observed; in the vicinity of the FAD at the west of the island, and in the north of the island, in a prospected environment rather oligotrophic.

The fish seemed interested only by the first scattering layer. It crossed this layer twice, the first time during daytime at about 200 - 250 m deep, and the second time during nighttime at about 150 m deep. Every time, the tuna changed its behavior, either for horizontal movements at daytime, or for vertical movements at nighttime.

It clearly appears that the whole set of movements observed during the free-swimming phase off FAD correspond to a foraging behavior (search for food, then feeding).

Echo-survey brings a new insight to the interpretation of classical results carried out through sonic tagging with pressure captors. This methodology should be used together with tags equipped with different captors (internal temperature, cardiac rhythm, electromyogram) as a tool for interpreting ecophysiology of the behavior.

Pelagic Fisheries Research at the South Pacific Commission

John Hampton

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The tuna fishery in the western Pacific Ocean increased rapidly during the 1980s. Since 1990, the annual catch has been stable at 1.2-1.4 million mt, around 40% of the world catch of primary market species. Skipjack and yellowfin make up 90% of the catch, much of which is caught by purse seiners. The south Pacific Commission's[1] Oceanic Fisheries Programme (OFP) and its predecessors have carried out data collection and research on the fishery since 1977. The OFP is organized into three major activity areas -- fisheries statistics, biological research and stock assessment and modelling.

Fisheries statistics. The OFP is responsible for the ongoing collection of fisheries statistics from tuna fishing activities in the EEZs of SPC member countries. Where possible, statistics for high seas areas and adjacent Southeast Asian areas are also collected. The major database, which has been maintained continuously since 1981, is the catch and effort logbook database. This database consists of set-by-set (or day-by-day) information for domestic and foreign licensed longline, purse seine and pole-and-line vessels fishing in the region. The current size of the database is approaching two million records. The OFP also maintains databases of aggregated data, usually consisting of 1° or 5° square-month summaries for individual fleets that represent total catch and effort throughout the whole region. The status of catch and effort data for the major fleets fishing in the western Pacific is as follows:

- *USA purse seine*: 100% logbook coverage since 1988, 1° square-month aggregate data 1981-1988.
- *Japan purse seine, pole-and-line, longline*: Nearly 100% logbook coverage of within-EEZ activities since the early 1980s, complete 1° square-month aggregate data for purse seine and pole-and-line fleets since 1967 and 1972, respectively, and complete 5° square-month aggregate data from the longline fleet since 1962.
- *Taiwan purse seine*: Nearly 100% logbook coverage in 1994, incomplete coverage pre-1994. Reliable estimates of total annual catches for all years.
- *Taiwan longline*: 5° square-month data since 1967, approximately 80% logbook coverage of small fresh-sashimi longliners based in Micronesia.
- *Korean purse seine*: Nearly 100% logbook coverage in 1994, incomplete coverage pre-1994. Reliable estimates of total annual catches for all years.
- *Korean longline*: 5° square-month or annual data since 1975, reasonably complete logbook coverage of within-EEZ activities.

Extensive collections of size composition data have also been complied, much of which has been collected and made available by various national fisheries agencies. The OFP has now established port sampling and observer programmes to collect size composition and other data from most fleets operating in the region.

[1] The South Pacific Commission is an international technical assistance agency serving independent Pacific Island countries and dependent territories in the South Pacific Region. Its members are American Samoa, Australia, Cook Islands, Federated States of Micronesia, Fiji, France, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Zealand, Niue, Northern Mariana Islands, New Caledonia, Palau, Papua New Guinea, Pitcairn Island (UK), Solomon Islands, Tokelau, Tonga, Tuvalu, USA, Vanuatu, Wallis & Futuna and Western Samoa.

Biological research. The OFP is currently undertaking, either alone or collaboratively, several projects on various aspects of the biology of western Pacific tunas. Their status is as follows:

- *Review of by-catch and discards*: The final report is in preparation for publication.
- *Age and growth of tropical tunas*: Daily periodicity of annuli on otoliths has been confirmed for yellowfin and is also likely for bigeye. Recruitment of a technician to undertake further otolith sample collection and analysis is underway.
- *Environmental determinants of tuna production*: The initial objectives of this activity are to (i) see if there is a link between patterns of primary productivity and hypothesized secondary productivity with the distribution of catch and CPUE; and (ii) determine relationships between fishery performance and various environmental parameters. See separate report.
- *Stock structure of bigeye tuna in the Pacific Ocean*: Bigeye stock structure is being investigated to see if western and eastern Pacific stocks are justifiable for the purposes of stock assessment. Sampling is almost completed and preliminary results are presented separately by our collaborating agency, CSIRO.

Stock assessment & modelling. The OFP undertakes population modelling and stock assessment using the various sources of data available. The major projects currently being pursued are:

- *Skipjack and yellowfin assessment using tagging data*: The Regional Tuna Tagging Project (RTTP) resulted in the release of approximately 140,000 tuna during 1989-1992, mostly skipjack and yellowfin. Returns to date number in excess of 18,000. These data, along with information on tag shedding and reporting rates, have been used to estimate mortality rates. The average exploitation rate (F/Z) for both species is approximately 0.2. For yellowfin, we have obtained mortality estimates by size class, which indicate much higher rates of natural mortally for small yellowfin.
- *Development of tuna movement models*: This ongoing research, utilizing the OFP's tagging and catch and effort databases, is being conducted collaboratively with the PFRP (see separate report).
- *Development of an integrated model for yellowfin assessment*: The objective of this project, which is supported by the PFRP, is to develop an age-structured model of western and central Pacific yellowfin that can be fit to catch and effort, size composition and tagging data (see separate report).
- *Bioeconomic modelling of western Pacific tuna fisheries*: This project is attempting to develop a framework for the estimation of optimal levels of effort in (i) the Solomon Islands purse seine and pole-and-line fishery, and (ii) the regional purse seine, pole-and-line and longline fishery. Our strategy in both cases is to develop models that simulate catch and economic performance as a function of effort. Both models have spatial structure and consider multiple gears and species. The regional model also incorporates age structure (see separate report). The project is a collaborative effort involving the OFP, the FFA and the University of Queensland.

Future direction:

Collection of fisheries statistics and research supporting stock assessment will continue, with this work likely to form the basis of scientific advice to new tuna fisheries management arrangements in the region. The nature of these arrangements will require the further development of spatial models of tuna stocks and fisheries. With the expansion of observer coverage, more emphasis is likely to be given to the estimation of by-catch and the impact of the fisheries on some of the important species.

Blue Marlin Popu n Genetic Structure in the Pacific Ocean: Analyses Mitochondrial and Nuclear DNA

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Restriction fragment length polymorphism (RFLP) analysis of mitochondrial (mt) DNA and anonymous single copy nuclear (scn) DNA is being used to investigate population structure of the blue marlin in the Pacific Ocean. Composite mtDNA haplotypes, representing digestion with 12 restriction endonucleases, have been generated for more than 200 blue marlin from four locations across the Pacific Ocean (Mexico, Ecuador, Hawaii, and Australia). High levels of mtDNA variation are present in all samples, with haplotype diversities (the probability of encountering different haplotypes in two draws from a sample) approaching 0.9. The distribution of mtDNA haplotypes among samples of blue marlin collected from Kona, Hawaii over a period of several years was temporally stable ($p=0.487$). Although significant differences exist in the distribution of mtDNA haplotypes between Pacific and Atlantic blue marlin ($p<0.001$), no significant geographic heterogeneity is evident among collections within the Pacific Ocean ($p=0.329$). The allele frequencies of three polymorphic anonymous nuclear loci were also stable at a single location between years, and did not vary markedly among samples from the Pacific Ocean (FST range 0.017 to 0.031). Based on these results we cannot reject the null hypothesis that blue marlin within the Pacific Ocean comprise a single genetic stock. These date contrast with the significant genetic heterogeneity revealed among samples of striped marlin from locations across the Pacific Ocean, and are consistent with sufficient exchange of blue marlin among geographically distant areas to prevent the accumulation of significant genetic divergence.

Global Population Structure of Swordfish, *Xiphias gladius*, as Revealed by Analysis of Mitochondrial DNA

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Little is known about what limits genetic exchange in highly vagile, open ocean vertebrate species such as the swordfish, *Xiphias gladius*. As a result, an accurate definition of population structure for this highly mobile species which supports a global fishery has been challenging to obtain. We have used mitochondrial DNA to assess the global population structure of swordfish. The patterns of sequence variation contained within the 5' end of the highly variable mitochondrial control region (D-loop) of a widespread global sample of 159 swordfish collected in three ocean basins: the Mediterranean (n=20), Atlantic (n=33) and the Pacific (n=105). Among the 159 individuals sequenced, 121 unique haplotypes were found, and overall haplotypic diversity was high (0.994). Only in the Mediterranean samples did we find an abundance of individuals from a single geographic locale with identical haplotypes (haplotypic diversity=0.832). Phylogenetic analysis of the relationships among the unique DNA haplotypes revealed two deeply divergent clades with differential geographic distributions, similar to what has been found for other istiophorid billfishes. The extent of global population subdivision was also examined using an analysis of molecular variance (AMOVA) framework. The results revealed significant geographic partitioning of molecular variance among the three ocean basins, indicating that swordfish populations are structured on a global scale. Based on the results from mtDNA control region data, the Pacific swordfish are composed primarily of a group of closely related individuals. Importantly, the AMOVA results were suggestive that eastern and western Pacific populations may be genetically distinct. This preliminary observation, which was based on a small sampling of Pacific swordfish, is being examined further with an extensive sampling of Pacific populations (n=300) and by sequencing longer sections of the control region.

Future work will target highly variable DNA loci (microsatellite loci) in the nuclear genome to study the population structure strictly within Pacific swordfish. Microsatellite loci can be highly informative and should permit discrimination between closely related groups allowing detection of population subdivision. Our research by the conclusion of this funding year will provide a geographical map outlining swordfish populations with corridors of gene flow (migration) and levels of genetic diversity (effective population sizes) marked so that fishery managers can easily interpret the genetic information and apply it to existing management programs.

Genetic Analysis of Tuna Populations

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The use of genetic techniques in fisheries management has changed dramatically since the electrophoresis of protein variants (allozymes) was first established as a tool for population genetics in the 1960s. For management of some species such as salmonids, the applications of these techniques have been very successful. However, stock structure has been somewhat difficult to resolve in marine species. Given that Australia has recently declared a 200 nautical mile Exclusive Economic Zone (EEZ), examining stock structure of commercially important marine species has greater urgency with regard to their effective management. The focus of this talk will be on research that examined nuclear (allozymes) and mitochondrial DNA (mtDNA) markers to reveal population structure of two commercially important tuna species in the Australian fishery, southern bluefin (SBT), and yellowfin (YFT).

Southern bluefin were collected from three regions (South Africa, Western Australia, and Tasmania). There were no observed allozyme allele or mtDNA haplotype frequency differences among any samples. These results indicated that southern bluefin appeared to constitute a single reproductive stock.

Yellowfin tuna were collected from 10 locations throughout its range (California, Gulf of Mexico, Coral Sea, Hawaii, Kiribati, Marshall Islands, Mexico, Philippines, Seychelles, and Sri Lanka). With the exception of the Seychelles (examined for mtDNA only), all fish were examined for variation of five polymorphic allozyme loci. Two restriction enzymes, which revealed useful polymorphisms, were used to characterize mtDNA haplotype variation. Allozyme data indicate the existence of at least four yellowfin stocks: Atlantic Ocean, Indian Ocean, west-central Pacific Ocean, and east Pacific Ocean. Furthermore, limited mtDNA differentiation was consistent with the identification of the Indian Ocean and Atlantic Ocean stocks as separate from the west-central Pacific stock, but was otherwise unable to discriminate eastern versus western Pacific stocks.

We are now examining DNA microsatellites for a more powerful examination of yellowfin population structure. Preliminary data from this study will be briefly outlined.

A molecular phylogeny based on examination of mitochondrial DNA will also be presented for the genus *Thunnus*. These data have proven extremely useful for the rapid and absolute identification of tuna to the species level for which visual identification was impossible.

Performance Indices for Hawaii's Troll and Handline Fisheries

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Commercial catches reported to the State of Hawaii's Division of Aquatic resources (HDAR) are the only continuous long-term time series of data on Hawaii's troll and handline fisheries. Troll and handline fishermen believe that their catch rates have declined as a result of increased fishing in Hawaiian waters in recent years. However, time-series analyses of these data do not show negative effects of increases in fishing. The validity of the HDAR data has been challenged in several ways which we have attempted to address. This presentation focuses on resolving two problems with the data: 1) lack of an explicit measure of effort in reporting catches by date, 2) lack of data on fishing days with no catch.

We used dates of catch from 1970-92 as a measure of effort (fishing days) and examined intervals between dates as a second variable. In 1978-79, catch per-days-fished (CPDF) was anomalous for catches reported one month apart, strongly suggesting that catches for many days fished were summed in monthly reports. The time series was improved by elimination of the monthly reports in those years. For other years CPDF data, stratified by intervals between reports, showed similar trends for different intervals. Thus, corrected CPDF data appear to provide a useful index of fluctuations in troll and handline fishery performance.

Frequency distributions of CPDF for any one species are sometimes highly skewed and include substantial frequencies of zero CPDF. A modified negative binomial distribution fit to the CPDF provided mean catch rates that differed very little from simple arithmetic means. Other analyses showed that mean CPDF, excluding days which caught no species at all, was highly predictive of mean CPDF including zero-catch days. Thus, lack of data on fishing days with no catch throughout much of the time series does not invalidate the use of CPDF as an index of fishery performance.

Simulation Modeling and Time Series Analysis of Catch and CPUE in Hawaii's Tuna Fisheries

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Commercial fisheries data are often used to evaluate fisheries impacts on fish populations. However, fisheries data often do not provide enough information for reliable estimation of the population parameters required to evaluate fisheries impacts using traditional stock assessment methods. In Hawaii, migration patterns of yellowfin tuna between the Hawaii Exclusive Economic Zone (EEZ) and other Pacific regions are poorly understood, as are other population parameters, such as natural mortality and catchability. Hawaii commercial fisheries data only provide time series of total catch and indices of catch per unit effort (CPUE).

This study examines a tool that can be used to estimate fisheries impacts on local fishery performance when only time series of catch and CPUE data are available. We used simulations to model relationships between total catch and CPUE in the Hawaii EEZ and patterns of these relationships under different scenarios of key parameters: migration rates, fishing mortality, and catchability. We then analyzed time series of total catch and CPUE produced by the models using time series transfer function models. We also applied the transfer function models to real commercial fisheries data from Hawaii's yellowfin tuna fisheries. Finally, we compared the results from the simulation models and the real fisheries data were used to estimate the power of the transfer function models to detect local fishery impacts.

In this study, the simulation models were run at monthly time steps for 30 years. The simulation models include stochastic processes in migration rates, fishing mortality, and catchability, and each scenario was simulated 1000 times. The transfer function model is a technique in time series analysis that is used to examine effects of the input variable (e.g., catch) on the output variable (e.g., CPUE) after the serial dependencies and seasonal trends in both series are removed. Total catches of yellowfin tuna from 1962 to 1994 were estimated from all fishing gears within the Hawaii EEZ, including longline, troll, and handline. CPUE for yellowfin tuna were separately estimated from troll and handline, and for two main Hawaiian islands.

Results indicated that total catches by Hawaii's fisheries had low probabilities of affecting local CPUE for yellowfin tuna. Further analysis will focus on time series of catch and CPUE estimated from the same fisheries, but at finer spatial and temporal scales, as we expect that fisheries would have higher probabilities of affecting local CPUE at finer scales.

Stock and Fishery Dynamics of Yellowfin Tuna, *Thunnus albacares*, in the Western and Central Pacific Ocean: An Integrated Model Incorporating Size and Spatial Structure

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The objectives of this two-year project are:

1. To develop a general model of the western and central Pacific Ocean (WCPO) yellowfin population and fishery, including size (age) and spatial structure; and
2. To use the model to investigate a series of related issues or questions that have important implications for current and future fisheries management.

During the first year, we plan to fit an age-structured model, previously applied to South Pacific albacore (the SPARCLE model), to the yellowfin data. The SPARCLE model attempts to estimate age composition from the size composition data, simultaneously estimating catchability and selectivity parameters for each fishery. A feature of the yellowfin data that was not encountered in the albacore analysis is multiple cohorts per year. We therefore need to extend the SPARCLE model to allow hypotheses regarding multiple cohorts to be tested. In the latter part of the first year and during year two, the SPARCLE model will be further extended to include spatial structure and fish movement.

In the short time so far available, we have attempted to get some appreciation for the scale of the yellowfin problem. A data set has been compiled consisting of:

- purse seine fisheries classified by set type (log or free school) and area
- longline fisheries classified by area
- Philippine domestic ringnet and handline fisheries
- Indonesian domestic fishery

The area stratification currently consists of the seven statistical areas defined by the Western Pacific Yellowfin Research Group. This results in a total of 16 "fisheries." The time period considered is from 1970 to 1994 in quarterly intervals, giving a total of 1,351 fishing incidents. The data associated with each fishing incident is catch in number, effort and a length frequency sample, although the latter two data items may be missing for some samples.

Initial fits to the yellowfin data indicate that a function evaluation takes approximately five minutes on a 100-mhz Pentium with 16 MB of RAM. With approximately 2,000 parameters to estimate, a complete fitting procedure would take around 100 hours. Given that this is a minimal data stratification for WCPO yellowfin and that additional model structure will be required to incorporate spatial effects, implementation of more powerful computer platforms, e.g. a Cray, will need to be investigated.

Automated Monitoring of Yellowfin Tuna at Hawaiian Fish Aggregation Devices (FADS)

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Eighteen yellowfin tuna (*Thunnus albacares*) were tagged with individually coded ultrasonic transmitters near Kaena Point, Oahu. Automated microprocessor-based monitors that detect these tags were attached to the Sierra, Romeo, and Victor FADs, oriented in a linear alignment parallel to the coast, and a subsurface buoy located at the edge of the submarine slope closest to V FAD and Kaena Point. Of the seven yellowfin tagged at FADs from 23 June to 1 Nov. 1995, individuals: 1) returned 1-3 times to the same FAD at which they were tagged after intervals of 1-12 days; 2) stayed for periods of 3-47 min. when at a FAD; 3) visited during two periods, more often during the morning (0433-0908 hrs) and less often in the evening (1955-2230 hrs); and 4) arrived at the FADs during rising tides. Two fish tagged in the morning at Victor FAD returned 5 days later within 3 min. of each other, indicating some school coherence over that time scale. Eleven yellowfin tuna, tagged at Kaena Point on 23 Aug. and 1 Sept. 1994, were not detected the following month by a monitor at Sierra FAD and monitors deployed nine months later at the three FADs and 12 months later at the mooring located near Kaena Point, despite a theoretical 12-month tag longevity. This absence of returns may be due to the above-observed site specificity. Before any conclusions are drawn regarding patterns of attendance, more yellowfin tuna must be tagged at the sites where these monitors are deployed.

The Reproductive Biology and Spawning Behavior of Yellowfin Tuna: Implications to Gear Vulnerability and Fishery Interaction

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The NOAA/JIMAR project #2060, Reproductive Biology of Yellowfin Tuna in Hawaiian Waters and the Western Tropical Pacific Ocean, has three main objectives: (1) examine and define the basic reproductive parameters of yellowfin tuna over a broad region of the central and western Pacific; (2) make comparisons between the reproductive parameters of surface and sub-surface caught yellowfin to address interaction issues; and (3) compare and contrast the primary region of yellowfin tuna spawning, which lies along the Equator, to a representative area of seasonal spawning activity, i.e., Hawaii.

Sampling for the project is derived completely from capture fisheries. Therefore, major sampling effort targets the western Pacific purse seine and longline fisheries, the sashimi handline fisheries of the Philippines and Indonesia and the longline, ika shibi handline and surface troll fisheries based in Hawaii.

The sampling methodology requires the collection of fresh yellowfin ovarian material by at-sea observers on commercial fishing vessels. Where observer programs are not available, material in suitable condition for histological analysis is collected by port sampling programs or contracted individuals. The interpretation of this material is used to determine the maturity, spawning frequency, time of spawning and other maturity stages. Batch fecundity estimates for different areas are determined by the extrapolation of oocyte counts from ovaries in hydrated condition. Fork lengths are recorded, and each sample is linked to a large data set which includes details on the date, time and area of capture, school type, fishing gear and environmental conditions at the time of capture.

Analysis of samples from western Pacific purse seine and longline fisheries supports the importance of an abundant forage source to maintain near daily spawning frequencies. Dense concentrations of pelagic baitfish concentrate tuna schools that engage in gorge feeding activity. The resulting boiling or foaming schools are often composed of mature, reproductively active fish that are highly vulnerable to purse seine gear. Large scale oceanographic processes that determine ENSO events appear to influence the area and season of peak baitfish abundance. The appearance of these dense concentrations of baitfish along the Equator has a significant influence on fishing mortality rates of sexually mature yellowfin by purse seine gear and likely coincides with major spawning events. Generally, the increase in surface setting by purse seine fleets and the utilization of shallow set longline gear by many longline fleets is increasing the rate of direct interaction between purse seine and longline gears along the Equator.

In Hawaiian waters, yellowfin concentrations close to the islands increase at the onset of the spawning season in April and May with water temperatures recorded to rise above 25^{o}C. Yellowfin in Hawaiian waters also exhibit near daily spawning frequencies during the middle of the summer spawning season. The active feeding required to fuel this reproductive activity increases their vulnerability to surface troll gear, shallow set longline gear and ika shibi handlines. During the spawning season, all three fisheries are in direct interaction with each other for mature, reproductively active yellowfin, except where area closures separate gear types.

Spawning occurs at night, mostly between sunset and midnight. Catch rates by night-set handline gear are low for this time period but increase between midnight and dawn which may be in response to an intense post-spawning period of active feeding. Shallow, night-set longline gear exhibiting high catch rates of yellowfin may be exploiting this phenomenon.

Feasibility of Airborne Laser Devices for Pelagic Fish Surveys

Chris Schoen

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This field test program entitled "Use of a Dual Mode Lidar for Pelagic Fish Surveys -- A Feasibility Demonstration" was conducted in support of the Pelagic Fisheries Research Program. The work was a portion of the effort entitled "Feasibility of Airborne Laser Devices for Pelagic Fish Surveys" under a Cooperative Agreement between the University of Hawaii and NOAA.

The SAIC "Dual Mode" Lidar system incorporated a Wideband Width Sensor (a gated PMT detector) and a Gated Imaging Sensor (an Intensified CCD Camera). The experimental Lidar of SAIC incorporated these two sensors coaxial with a 90/10 split in received energy. These channels used a 3-nm bandwidth optical filter at the input. The source was a 70 mj Q-switched and doubled Nd:YAG laser operated parallel but not coaxial with the receiver. The laser divergence was variable with the baseline established to provide a subsurface 6-foot beam at a 35-foot depth.

The experiment was conducted at the NRaD TRANSDEC tank (San Diego) which is 40 feet deep and approximately 250 feet in diameter. The Lidar was mounted at the tank center on an existing bridge and the beam was directed downward into the tank with a turning mirror. The tank water was quite turbid with a measured K of 0.147. Targets were deployed at about 12-meter depths to start and then were extended to 33 meters with the subsurface deployed mirror.

The experiment was conducted out to ranges which exceeded the fish identification range but detection was possible over ranges exceeding this identification range. Identifiable targets were recorded at ranges of 27 m for this turbid water (which corresponded to 3.4 attenuation lengths) equivalent to 62.5 m or 205 feet in typical ocean "blue" water where K = 0.054. Detection by both sensors exceeded 32 m (4.85 attenuation lengths) or better than 294 feet for blue water. Fish detection depth limits were determined through extrapolation of data to be up to 500 foot depths in blue water.

Identification at depths of 300 feet for blue water is important since during daylight hours it has been shown that yellowfin tuna, for instance, cycle at depths from 150 feet to 450 feet. During nighttime hours, these same fish cycle at depths from 0 feet to 300 feet.

A competing technology to Lidar is passive systems. Hyperspectral systems have shown a great utility of late. However, these systems are shown to be limited to approximately 150-foot depths during daylight hours and, obviously, do not work well during nighttime hours.

It has been proposed that future work would concentrate on combining Lidar with Hyperspectral to be able to analyze fluorescence signatures of fish at depths of up to 300 feet.

Preliminary Estimation of Shark Bycatch by the Hawaii Longline Fishery

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This is the first report of the project "Estimation of bycatch and discards of sharks and other species by the Hawaii longline fishery" funded by the Pelagic Fisheries Research Program. The project began in September of 1995. The goals of this project are to estimate bycatch and discards by the Hawaii longline fishery from 1991 to 1995; to understand the effects of fishing methods, area, and season on bycatch; and, ultimately, to estimate the impacts on the bycatch populations, particularly on blue shark (*Prionace glauca*).

Bycatch is defined as catch of non-target species, whereas discard is the portion of the total catch that is discarded. Data used for the estimation are the longline logbook data and observer data. Logbook data are reported by commercial fishermen themselves and observer data are collected by NMFS employees on commercial vessels. Although the observer data are accurate, only about 6% of total fishing trips were covered. The logbook data contained information on all trips, but must be evaluated as to the completeness of reporting.

I present results of (1) comparisons of catches of target species and bycatch between the logbook data and the observer data; and (2) preliminary estimation of shark bycatch by the Hawaii longline fishery from January of 1991 to August of 1995 based on the logbook data. Spatial, temporal, and gear-related patterns of shark bycatch are presented. These estimations are preliminary, since the under-reporting problem of bycatch in the logbook data has not been resolved.

Aspects of the Ecology of the Red Squid, *Ommastrephes bartramii*, a Potential Target for a Major Hawaiian Fishery

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The red squid, *Ommastrephes bartramii*, is found throughout the subtropical and temperate regions of the world's oceans, although the North Pacific population is thought to be genetically distinct. The North Pacific fishery for O. bartramii began in the late 1970s. By the late 1980s the yearly catch was approximately 350 million mt and most squid were caught by driftnets. Since the moratorium on driftnet fishing at the end of 1992, the central North Pacific fishery has virtually disappeared. We suspect that adults of this now underutilized, major resource migrate into or near the Hawaiian EEZ during the winter and are available to Hawaiian fishermen.

We will investigate the winter distribution of the adults, which is poorly known, and the factors responsible for this distribution. Specifically, we will (1) determine if an increase in abundance of red squid exists along northward transects from Hawaii to 300°N lat.; (2) determine the squid abundance in the vicinity of 300°N; (3) investigate latitudinal changes in feeding by determining changes in prey and stomach fullness; (4) determine latitudinal changes in reproduction by examining reproductive states of mature females and sampling paralarvae; (5) investigate various parameters needed for understanding the population dynamics of this species. These include studies of fecundity by examining the mode of spawning, batch fecundity, and percent of first-time spawners in the population; studies of paralarval survival through rearing experiments; studies of the value of statoliths for routine age determinations and timing of life-history events.

Sampling will be done in cooperation with scientists from Hokkaido University aboard their ship FTV HOKUSEI MARU during a two-week cruise in February each year. Adult squids will be caught with squid-jig driftlines and paralarvae with plankton nets. We also hope to provide jigs to some swordfish/albacore fishermen who are fishing the subtropical frontal region and, in return, obtain stomach samples and catch-per-effort data.

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